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13. ABSTRACT (Maximum 200 words)
The attached report describes active vibration control in helicopter fuselages using the ACSR (Active Control of Structural Response) approach. In this approach the vibration reduction is carried out by using four actuators in the fuselage. The fuselage is modeled by finite elements. The vibratory aerodynamic loads include a free wake combined with rotor/fuselage interactional aerodynamics. An improved control algorithm preferentially reduces accelerations at selected airframe locations where vibration levels are important. Fuselage vibrations are reduced below 0.05g at all locations.

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FINAL TECHNICAL REPORT FOR THE ACTIVITIES CONDUCTED UNDER ASSERT GRANT NO. DAAH04-95-1-0320 FOR THE PERIOD 6/1/96-5/31/2000

GRANT TITLE: VIBRATION REDUCTION IN ROTORCRAFT USING THE ACSR WITH ENHANCED AERODYNAMIC AND CONTROL MODELING

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Introduction and Background

This grant was initially funded 6/1/95 and a very capable Ph. D. student (Matthew Kropp) was hired and started his studies towards a Ph. D. degree working in the area of vibration reduction in helicopters. Unfortunately around November 1995 Matthew became involved with a start-up company developing software for the Internet and shortly afterward (January 20, 1996) he resigned from the University after deciding to devote all his time to the new company that he started with two other friends. Subsequently, a search for another talented Ph. D. student, who was a U. S. citizen, was conducted. Almost a year later (March 1, 1997) a new student was successfully recruited. The new student, Richard Cribbs, had exceptional qualifications (GPA of 4.0/4.0), he has passed his Ph. D. preliminary written exam in May 1997.

Richard Cribbs has been working on the topic of the ASSERT grant, namely, vibration reduction in helicopter fuselages using the active control of structural response (ACSR) approach, since March 1997. The fundamental aspects of this approach were developed and studied under the auspices of the parent grant. The objectives of the current grant were to develop a much more realistic model for the aerodynamic loading acting on the coupled rotor/flexible fuselage aeroelastic system, which accounts for both blade vortex interaction (BVI) and rotor/fuselage interactional aerodynamics. This research activity also required the consideration of new control algorithms, which are used for vibration reduction in the flexible fuselage. Richard was the best Ph. D. student that I have had in the last ten years and he has written an outstanding Ph. D. dissertation combined with several papers (see Refs. 1-6 at the end of this report). Dr. Cribbs received his Ph. D degree from UCLA in August of 1999. Subsequently he spent one year with me at the

* Active Control of Structural Response

University of Michigan as a postdoctoral scholar. Since August 2000 he has been working as a Dynamics Engineer at Sikorsky Aircraft Co. It should be noted that as a result of the expeditious manner in which Dr. Cribbs dissertation was completed and my move to the University of Michigan, $18,000 of grant funds that were not used have been returned to the funding agency. The research carried out under the grant and the principal accomplishments are summarized in the following sections.

Summary of Research Conducted

In this research the fuselage of the helicopter is modeled by a three-dimensional structural dynamic finite element model, and it is combined with a flexible four (or five bladed) hingeless rotor, see Fig. 1, at the end of this document. Each rotor blade is structurally modeled as an isotropic Euler-Bernoulli beam with coupled flap-lag-torsional dynamics assuming moderate deflections. A free wake model is incorporated into the aeroelastic response model and is validated against previous studies. Two and three-dimensional sources are used to model the fuselage aerodynamics. Direct aerodynamic influences of the rotor and wake on the fuselage are calculated by integrating pressures over the surface of the fuselage. The fuselage distorts the wake and influences the air-velocity components at the rotor, which in turn modify the aerodynamic loading. This produces fully coupled rotor/fuselage aerodynamic interactions. A schematic representation of the rotor/fuselage interactional aerodynamics is depicted in Figs. 2 and 3.

The influence of the aerodynamic refinements on vibrations is studied in detail. Results indicates that the free wake model and the inclusion of the fuselage aerodynamic effects on the rotor and wake are required for accurate vibration prediction at all forward flight speeds. The direct influence of rotor and wake aerodynamics on the fuselage plays a minor role in vibrations. Acceleration levels with the improved aerodynamic model are significantly greater than results based on uniform inflow. The influence of vertical separation between the rotor and the fuselage on vibrations is also studied.

An ACSR algorithm is developed that preferentially reduces accelerations at selected airframe locations where vibration levels are important. Vibration reduction studies are carried out using this improved control algorithm as well as a basic control algorithm studied previously at UCLA. Both ACSR methods markedly reduce acceleration amplitudes with no impact on the rotor system or the airworthiness of the vehicle. The improved control algorithm performs significantly better than the basic control method, while maintaining equally low power requirements.

Principal Accomplishments

The results generated in this study were for a medium type helicopter having a four bladed soft-in-plane hingeless rotor, and they are indicative of trends that could also apply to other configurations. The results documented in Refs. 1- 6, below are indicative of the following conclusions:

- The refined aerodynamic models significantly affect the vibratory loads transferred from the rotor to the fuselage and the accelerations experienced at the various fuselage locations.
- The refined aerodynamic model is required for accurate vibration prediction and control at all advance ratios.
- Increasing the separation between the rotor and the fuselage reduced all components of fuselage vibrations, the optimal separation was approximately 20% of rotor radius.
- Remarkable vibration reduction through the use of ACSR is possible at all advance ratios, with acceleration levels reduced below 0.05g at all fuselage locations.
- Power requirements for vibration reduction are quite low, and these never exceed 1.5% of rotor power.
- Since the ACSR system achieves vibration reduction in the non-rotating or fixed system, it has no impact on vehicle airworthiness.
- The ACSR system requires high force, small displacement actuators.
- The weighted control algorithm with control penalty was capable of reducing accelerations at desired fuselage locations, significantly below the accelerations of the basic control scheme using similar actuator forces and power. The accelerations obtained using the weighted controller were up to 82% below the accelerations achieved with the basic controller.

PUBLICATIONS GENERATED UNDER THIS GRANT

1. Cribbs, R.C. and Friedmann, P. P., "Vibration Suppression in Helicopters Using the ACSR Approach with Improved Aerodynamic Modeling", AIAA Paper No. 99-1218, Proceedings of 40th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, St. Louis, MO, April 12-115, 1999, pp. 110-125.

2. Cribbs, R.C. and Friedmann, P. P., "Vibration Suppression in Helicopters with ACSR Approach Using an Improved Control Algorithm", Proceedings of the 25th European Rotorcraft Forum, Paper No. G. 14, Rome, Italy, September 14-16, 1999, pp. G.14.1-14.

3. Cribbs, R. And Friedmann, P. P., "Vibration Reduction in Rotorcraft Using an Enhanced ACSR Model", AIAA Paper 2000-1687, Proceedings of 41st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, Atlanta, Georgia, April 3-6, 2000.

4. Cribbs, R.C., Friedmann, P. P. and Chiu, T., "Coupled Helicopter Rotor/Flexible Fuselage Aeroelastic Model for Control of Structural Response", AIAA Journal, Vol. 38, No. 10, October 2000, pp. 1777-1788.

5. Cribbs, R.C., " Vibration Reduction in Helicopters Using Active Control of Structural Responase (ACSR) with Improved Aerodynamic Modeling", Ph. D. Dissertation, Mecahnical and Aerospace Engineering Department, University of California, Los Angeles, December 1999.

6. Cribbs, R. C. and Friedmann, P. P., "Vibration Reduction in Rotorcraft Using an Enhanced ACSR Model", Paper submitted to the AHS Journal, 2000.

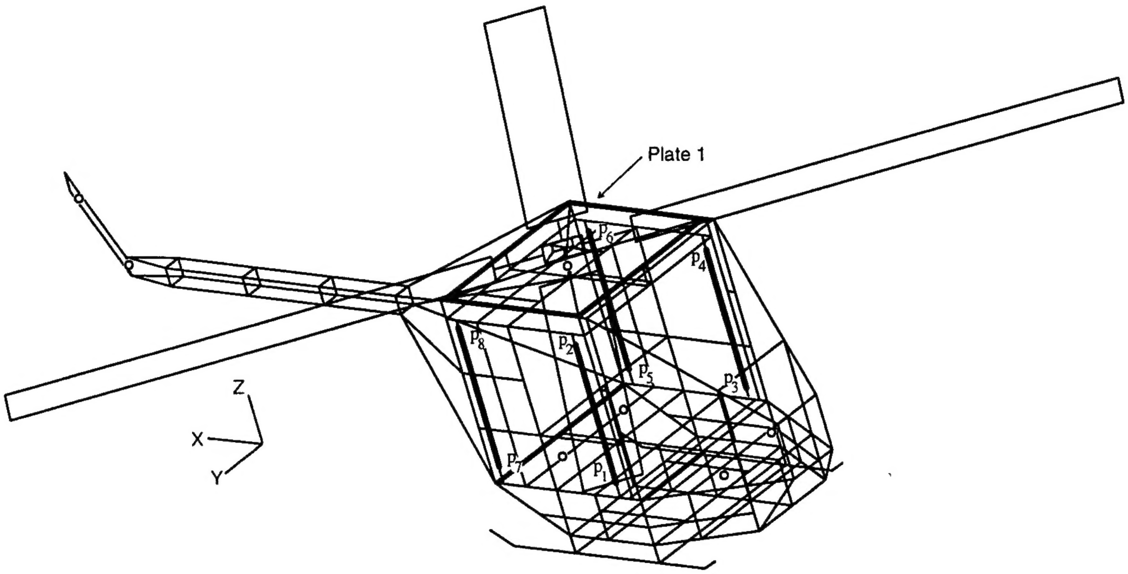

Fig. 1 Coupled rotor / flexible fuselage / active control dynamic system used for ACSR simulations.

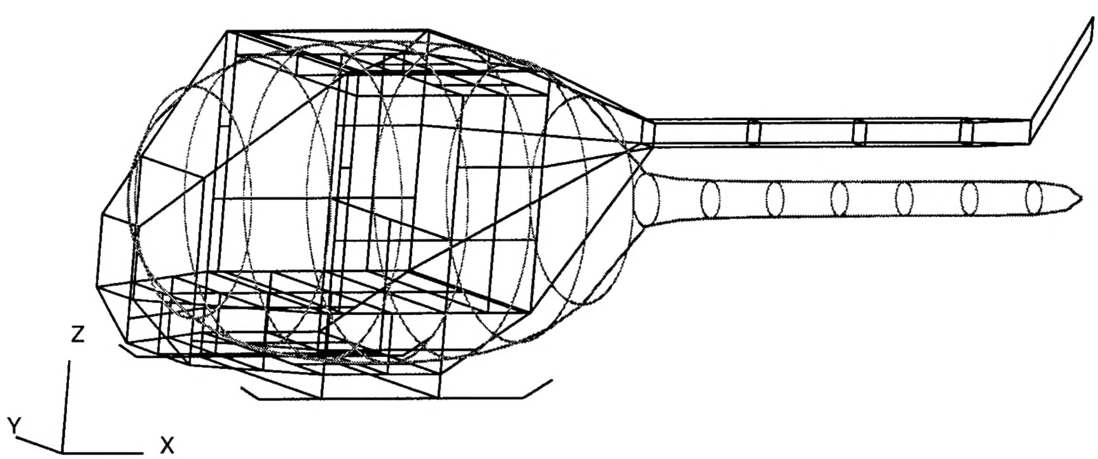

Fig. 2 Body of revolution / fuselage comparison.

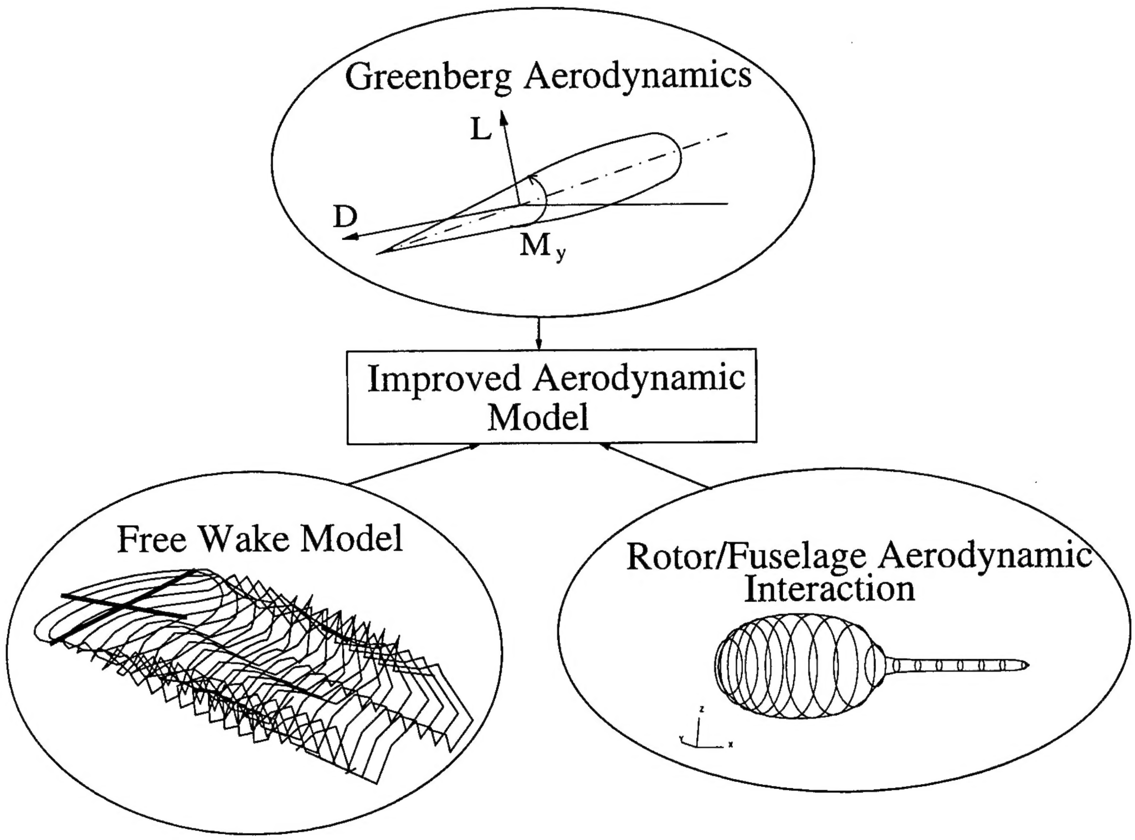

Fig. 3 Schematic description of the elements combined to obtain the improved aerodynamic model that accounts for rotor/fuselage aerodynamic interaction.